WHAT IS CLAIMED IS:

1. A fuel reforming apparatus for producing a hydrogen-rich gas from a hydrocarbon-based fuel by means of a reforming reaction, the fuel reforming apparatus comprising:

a fuel decomposition unit configured to decompose a first hydrocarbon-based fuel into a second hydrocarbon-based fuel with a lower carbon number; and

a reforming reactor having a reforming catalyst for promoting a reforming reaction, the reforming reactor being configured to produce a hydrogen-rich gas from the second hydrocarbon-based fuel by the reforming reaction.

2. A fuel reforming apparatus as defined in Claim 1, wherein the decomposition in the fuel decomposition unit is performed by pyrolysis.

3. A fuel reforming apparatus as defined in Claim 2, further comprising:

oxygen supply means for feeding oxygen to the fuel decomposition unit,

wherein the fuel decomposition unit is configured to operate such that the oxygen fed by the oxygen supply means is used to partially oxidize the first hydrocarbon-based fuel, and heat evolved by the oxidation is used to pyrolyze the remaining first hydrocarbon-based fuel.

4. A fuel reforming apparatus as defined in Claim 3, wherein the fuel decomposition unit comprises a controller for controlling reaction conditions in the fuel decomposition unit such that the decomposition reaction of the first hydrocarbon-based fuel proceeds at a desired level while formation of soot that accompanies the decomposition of the first hydrocarbon-based fuel is suppressed during the decomposition of the first

hydrocarbon-based fuel.

5. A fuel reforming apparatus as defined in Claim 4, wherein the controller regulates a rate of entire reaction occurring in the fuel decomposition unit in response to a feed rate of the first hydrocarbon-based fuel fed to the fuel decomposition unit.

6. A fuel reforming apparatus as defined in Claim 5, wherein the controller regulates the rate of the entire reaction by controlling a ratio of an amount of oxygen fed to the fuel decomposition unit to an amount of carbon in the first hydrocarbon-based fuel.

7. A fuel reforming apparatus as defined in Claim 5, wherein the controller regulates the rate of the entire reaction by controlling a temperature inside the fuel decomposition unit.

8. A fuel reforming apparatus as defined in Claim 7, wherein the controller controls the temperature inside the fuel decomposition unit by controlling a temperature of gas fed to the fuel decomposition unit.

9. A fuel reforming apparatus as defined in Claim 8, wherein the gas fed to the fuel decomposition unit includes plural types of gases containing oxygen and vaporized first hydrocarbon-based fuel; and

the controller controls a temperature of at least one gas selected from among the plural types of gases fed to the fuel decomposition unit.

10. A fuel reforming apparatus as defined in Claim 4, wherein the controller regulates a residence time of fluids in the fuel decomposition unit in response to a feed rate of the first hydrocarbon-based fuel fed to the fuel decomposition unit.

11. A fuel reforming apparatus as defined in Claim 10, wherein the controller regulates the residence time by controlling a pressure inside the fuel decomposition unit.

12. A fuel reforming apparatus as defined in Claim 10, further comprising:

steam supply means for feeding steam to the fuel decomposition unit,

wherein the controller regulates the residence time by controlling a ratio of an amount of steam fed to the fuel decomposition unit to an amount of carbon in the first hydrocarbon-based fuel.

13. A fuel reforming apparatus as defined in Claim 12, wherein the controller regulates the residence time by controlling a volume of space in which reactions are actually conducted using the first hydrocarbon-based fuel in the fuel decomposition unit.

14. A fuel reforming apparatus as defined in Claim 4, wherein the fuel decomposition unit operates such that the first hydrocarbon-based fuel is pyrolyzed to produce the second hydrocarbon-based fuel while the first hydrocarbon-based fuel is passing through the fuel decomposition unit; and

the controller operates such that a reaction-terminating gas whose temperature is less than a temperature inside the fuel decomposition unit is fed to a specified location inside the fuel decomposition unit, thereby suppressing progress of unwanted reactions connected to soot formation downstream of the specified location.

15. A fuel reforming apparatus as defined in Claim 14, wherein the reaction-terminating gas is air and/or steam.

16. A fuel reforming apparatus as defined in Claim 14, further comprising:

water spraying means for spraying water at the specified location inside the fuel decomposition unit, the water sprayed by the water spraying means being vaporized inside the fuel decomposition unit to produce steam serving as the reaction-terminating gas.

17. A fuel reforming apparatus as defined in Claim 3, wherein the fuel decomposition unit comprises temperature distribution averaging means for averaging out temperature distribution within the fuel decomposition unit in a direction of gas flow.

18. A fuel reforming apparatus as defined in Claim 17, wherein the temperature distribution averaging means includes heat transfer means for transferring heat evolved in an active region of oxidation reaction of the first hydrocarbon-based fuel to a less active region of the oxidation reaction in the fuel decomposition unit.

19. A fuel reforming apparatus as defined in Claim 17, wherein the temperature distribution averaging means includes first divisional supply means for divisionally feeding the first hydrocarbon-based fuel to separate locations along a direction of gas flow in the fuel decomposition unit.

20. A fuel reforming apparatus as defined in Claim 17, wherein the temperature distribution averaging means includes second divisional supply means for divisionally feeding oxygen to separate locations along a direction of gas flow in the fuel decomposition unit.

21. A fuel reforming apparatus as defined in Claim 1, wherein the fuel decomposition unit comprises a controller for controlling reaction conditions in the fuel decomposition unit such that the decomposition reaction of the first hydrocarbon-based fuel proceeds at a desired level while formation of soot that accompanies the decomposition of the first

hydrocarbon-based fuel is suppressed during the decomposition of the first hydrocarbon-based fuel.

22. A fuel reforming apparatus as defined in Claim 1, wherein the fuel decomposition unit includes a catalyst for promoting the decomposition reaction of the first hydrocarbon-based fuel.

23. A fuel reforming apparatus as defined in Claim 1, wherein the fuel decomposition unit includes a plasma-generating unit configured to generate a low-temperature plasma designed to promote the decomposition reaction of the first hydrocarbon-based fuel.

24. A fuel reforming apparatus as defined in Claim 1, wherein the first hydrocarbon-based fuel is a higher hydrocarbon-based fuel with a carbon number of 4 or greater.

25. A fuel reforming apparatus as defined in Claim 24, wherein the higher hydrocarbon-based fuel is a hydrocarbon-based fuel selected from gasoline, naphtha, and light oil.

26. A fuel reforming apparatus as defined in Claim 1, further comprising supplementary feeding means for feeding the reforming reactor with steam and/or oxygen-containing gas separately from gas containing the second hydrocarbon-based fuel supplied from the fuel decomposition unit.

27. A fuel reforming apparatus as defined in Claim 26, wherein the supplementary feeding means feeds steam to the reforming reactor; and

the steam fed to the reforming reactor by the supplementary feeding means is sprayed in liquid state inside the reforming reactor and vaporized by heat of the gas containing the second hydrocarbon-based fuel supplied from the fuel decomposition unit.

28. A fuel reforming apparatus as defined in Claim 3, wherein the oxygen supply means comprises:

first oxygen supply means for supplying oxygen at an upstream side of the fuel decomposition unit to cause oxidation of the first hydrocarbon-based fuel, thereby starting the decomposition reaction; and

second oxygen supply means for adding oxygen at a downstream side of the fuel decomposition unit for the oxidation of the first hydrocarbon-based fuel.

29. A fuel reforming apparatus as defined in Claim 3, further comprising:

a heater for producing heat by oxidation reaction and heating the first hydrocarbon-based fuel before being fed to the fuel decomposition unit; and

exhaust gas supply means for supplying an exhaust gas produced by the oxidation reaction in the heater to the fuel decomposition unit.

30. A fuel reforming apparatus as defined in Claim 2, further comprising temperature increase promoting means for promoting an increase in an internal temperature near an inlet portion of the fuel decomposition unit.

31. A fuel reforming apparatus as defined in Claim 1, further comprising a mixing unit configured to mix fluids to be fed to the fuel decomposition unit in gaseous state before being fed to the fuel decomposition unit.

32. A fuel reforming apparatus for producing hydrogen-rich gas from a hydrocarbon-based fuel by means of a reforming reaction, comprising:

a reforming reactor having a reforming catalyst for promoting the

reforming reaction; and

means for feeding the hydrocarbon-based fuel to the reforming reactor,

wherein the reforming reactor maintains activity of the reforming reaction occurring on a surface of the reforming catalyst while suppressing unwanted gas-phase reactions occurring in the reforming reactor off the surface of the reforming catalyst.

33. A fuel reforming apparatus as defined in Claim 32, wherein the reforming reactor includes a porous article or a honeycomb tube whose surface is used to support the reforming catalyst, and the gas-phase reactions are suppressed by providing the porous article or the honeycomb tube with sufficiently small size.

34. A fuel reforming apparatus as defined in Claim 32, wherein the reforming reactor is designed to control the gas-phase reactions by selecting a sufficiently low value for a ratio L/D, L denoting a length of a flow passage of the hydrocarbon-based fuel in the reforming reactor, D denoting a cross-sectional diameter of the flow passage of the hydrocarbon-based fuel in the reforming reactor.

35. A fuel reforming apparatus as defined in Claim 32, wherein the hydrocarbon-based fuel is a higher hydrocarbon-based fuel with a carbon number of 4 or greater.

36. A fuel reforming apparatus as defined in Claim 35, wherein the hydrocarbon-based fuel is a hydrocarbon-based fuel selected from gasoline, naphtha, and light oil.

37. A fuel reforming apparatus as defined in Claim 32, further comprising a mixing unit configured to mix fluids to be fed to the reforming

reactor in gaseous state before being fed to the reforming reactor.

38. A fuel cell system comprising:

a fuel cell for generating electromotive force by electrochemical reactions; and

a fuel reforming apparatus for producing a hydrogen-rich gas from a hydrocarbon-based fuel by means of a reforming reaction, and supplying the hydrogen-rich gas to the fuel cell,

the fuel reforming apparatus comprising:

a fuel decomposition unit configured to decompose a first hydrocarbon-based fuel into a second hydrocarbon-based fuel with a lower carbon number; and

a reforming reactor having a reforming catalyst for promoting a reforming reaction, the reforming reactor being configured to produce a hydrogen-rich gas from the second hydrocarbon-based fuel by the reforming reaction.

39. A fuel cell system comprising:

a fuel cell for generating electromotive force by electrochemical reactions; and

a fuel reforming apparatus for producing a hydrogen-rich gas from a hydrocarbon-based fuel by means of a reforming reaction, and supplying the hydrogen-rich gas to the fuel cell,

the fuel reforming apparatus comprising:

a fuel decomposition unit configured to decompose a first hydrocarbon-based fuel by means of pyrolysis into a second hydrocarbon-based fuel with a lower carbon number;

a reforming reactor having a reforming catalyst for promoting a reforming reaction, the reforming reactor being configured to produce a hydrogen-rich gas from the second hydrocarbon-based fuel by the reforming reaction; and

oxygen supply means for feeding oxygen to the fuel decomposition unit,

wherein the fuel decomposition unit is configured to operate such that the oxygen fed by the oxygen supply means is used to partially oxidize the first hydrocarbon-based fuel, and heat evolved by the oxidation is used to pyrolyze the remaining first hydrocarbon-based fuel, and

wherein the oxygen supply means supplies a cathode off-gas discharged from the fuel cell to the fuel decomposition unit as part of the oxygen fed to the fuel decomposition unit.

40. A fuel cell system as defined in Claim 39, wherein the oxygen supply means can feed both the cathode off-gas and air to the fuel decomposition unit in order to provide the fuel decomposition unit with oxygen; and

wherein the oxygen supply means includes an oxidation gas controller for controlling a ratio of the cathode off-gas and air supplied to the fuel decomposition unit.

41. A fuel cell system comprising:

a fuel cell for generating electromotive force by electrochemical reactions; and

a fuel reforming apparatus for producing a hydrogen-rich gas from a hydrocarbon-based fuel by means of a reforming reaction, and supplying the hydrogen-rich gas to the fuel cell,

the fuel reforming apparatus comprising:

a fuel decomposition unit configured to decompose a first hydrocarbon-based fuel by means of pyrolysis into a second hydrocarbon-based fuel with a lower carbon number;

a reforming reactor having a reforming catalyst for promoting a reforming reaction, the reforming reactor being configured to produce a hydrogen-rich gas from the second hydrocarbon-based fuel by the

reforming reaction; and

oxygen supply means for feeding oxygen to the fuel decomposition unit,

wherein the fuel decomposition unit is configured to operate such that the oxygen fed by the oxygen supply means is used to partially oxidize the first hydrocarbon-based fuel, and heat evolved by the oxidation is used to pyrolyze the remaining first hydrocarbon-based fuel, and

wherein the fuel reforming apparatus further comprises anode off-gas supply means for supplying an anode off-gas discharged from the fuel cell to the fuel decomposition unit.

42. A fuel cell system as defined in Claim 41, wherein the anode off-gas supply means comprises an anode off-gas flow rate controller for controlling a feed rate of the anode off-gas fed to the fuel decomposition unit in response to a feed rate of the first hydrocarbon-based fuel fed to the fuel decomposition unit.

43. A fuel cell system comprising:

a fuel cell for generating electromotive force by electrochemical reactions; and

a fuel reforming apparatus for producing a hydrogen-rich gas from a hydrocarbon-based fuel by means of a reforming reaction, and supplying the hydrogen-rich gas to the fuel cell,

the fuel reforming apparatus comprising:

a fuel decomposition unit configured to decompose a first hydrocarbon-based fuel by means of pyrolysis into a second hydrocarbon-based fuel with a lower carbon number; and

a reforming reactor having a reforming catalyst for promoting a reforming reaction, the reforming reactor being configured to produce a hydrogen-rich gas from the second hydrocarbon-based fuel by the reforming reaction,

wherein the fuel decomposition unit comprises a heat exchanger capable of exchanging heat with a specified high-temperature fluid discharged from a specified location inside the fuel cell system such that the pyrolysis is accomplished using the heat obtained by heat exchange with the specified high-temperature fluid.

44. A fuel cell system as defined in Claim 43, further comprising a complete oxidation unit configured to completely oxidize a same type of first hydrocarbon-based fuel as that decomposed in the fuel decomposition unit, thereby producing the high-temperature fluid including a completely oxidized gas.

45. A fuel cell system as defined in Claim 43, wherein the high-temperature fluid is an oxidized gas obtained by oxidizing hydrogen in an anode off-gas discharged from the fuel cell.

46. A fuel cell system as defined in Claim 43, further comprising a heater for producing heat by oxidation reaction and heating the first hydrocarbon-based fuel before being fed to the fuel decomposition unit,

wherein the high-temperature fluid is an oxidized gas produced by the oxidation in the heater.

47. A fuel cell system comprising:

a fuel cell for generating electromotive force by electrochemical reactions, and

a fuel decomposition unit configured to decompose a first hydrocarbon-based fuel into a second hydrocarbon-based fuel with a lower carbon number, the second hydrocarbon-based fuel being fed to the fuel cell to cause the electrochemical reactions.

48. A fuel cell system as defined in Claim 47, wherein the fuel cell

is a high-temperature fuel cell; and

the fuel decomposition unit decompose the first hydrocarbon-based fuel by pyrolysis, the pyrolysis being promoted by heat generated by the fuel cell.

49. A fuel cell system as defined in Claim 48, wherein the fuel cell is configured such that oxide ions move across an electrolyte.

50. A fuel cell system as defined in Claim 47, wherein the first hydrocarbon-based fuel is a higher hydrocarbon-based fuel with a carbon number of 4 or greater.

51. A fuel reforming method for producing a hydrogen-rich gas from a hydrocarbon-based fuel, comprising the steps of:

(a) decomposing a first hydrocarbon compound into a second hydrocarbon-based fuel with a lower carbon number; and

(b) producing a hydrogen-rich gas from the second hydrocarbon-based fuel by a reforming reaction.

52. A fuel reforming method as defined in Claim 51, wherein the decomposition of the first hydrocarbon-based fuel is performed by pyrolysis.

53. A fuel reforming method as defined in Claim 52, wherein the step (a) comprises the steps of:

(a-1) oxidizing a same type of hydrocarbon-based fuel as the first hydrocarbon-based fuel, thereby generating heat; and

(a-2) pyrolyzing the first hydrocarbon-based fuel by employing the heat generated in the step (a-1).

54. A fuel reforming method for producing a hydrogen-rich gas from a hydrocarbon-based fuel by means of a reforming reaction, characterized in

that:

the reforming reaction proceeds on a surface of a reforming catalyst sufficiently active to promote the reforming reaction; and

the reforming reaction is kept active while unwanted gas-phase reactions occurred in a gas phase off the surface of the reforming catalyst are adequately suppressed.

55. A method for starting up a fuel cell system, the fuel cell system comprising a fuel cell, and a fuel decomposition unit configured to receive a supply of oxygen and first hydrocarbon-based fuel, and to partially oxidize the first hydrocarbon-based fuel using the oxygen, and to pyrolize the remaining first hydrocarbon-based fuel using oxidation-evolved heat to thereby produce a second hydrocarbon-based fuel with a lower carbon number, the second hydrocarbon-based fuel being fed to the fuel cell from the fuel decomposition unit, characterized by

raising a ratio of an amount of oxygen to an amount of the first hydrocarbon-based fuel fed to the fuel decomposition unit until the fuel cell is heated up to a specified temperature, thereby adequately causing partial oxidation of the first hydrocarbon-based fuel in the fuel decomposition unit and promoting oxidation of hydrogen and carbon monoxide produced by the partial oxidation reaction on an anode-side catalyst inside the fuel cell.